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Utilization of Excess Wind Power in Electric Vehicles

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# Utilization of Excess Wind Power in Electric Vehicles

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## Abstract

This article describes the assessment of future wind power utilization for charging electric vehicles (EVs) in Germany. The potential wind power production in the model years 2020 and 2030 is derived by extrapolating onshore wind power generation and offshore wind speeds measured in 2007 and 2010 to the installed onshore and offshore wind turbine capacities assumed for 2020 and 2030. The energy consumption of an assumed fleet of 1 million EVs in 2020 and 6 million in 2030 is assessed using detailed models of electric vehicles, real world driving cycles and car usage.

It is shown that a substantial part of the charging demand of EVs can be met by otherwise unused wind power, depending on the amount of conventional power required for stabilizing the grid. The utilization of wind power is limited by the charging demand of the cars and the bottlenecks in the transmission grid. However, the recent grid development plan is designed to remove most of these grid bottlenecks.

## Keywords

wind power; electric vehicles; V2G vehicle-to-grid

## Results of the NET-ELAN project

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## I Introduction

Electric vehicles (EVs) raise the expectation that they can also be used as storage for intermittent electricity production from renewable energies (wind and solar). This was mentioned as early as 2002 [Kempton & Letendre, 2002] and also found its way into the energy concept of the German Federal Government [BMW & BMU, 2010]. To investigate the effects of a fleet of EVs in Germany, the NET-ELAN project was initiated, funded by the German Federal Ministry of Economics and Technology. It covers a broad field of topics:

- Development trends of the electric grid and the power plant pool,
- development trends of future EV designs and determination of battery requirements and energy demand [Waldowski et al., 2010],
- scenarios of future energy supply and build-up of an EV fleet,
- assessment of spatial and temporal distributions of EVs connected to the grid [Linssen et al., 2011],
- grid integration of EVs with regard to feasibility, energy demand [Hennings & Linssen, 2010], emissions, and cost aspects [Bickert et al., 2011], including battery durability [Günther et al., 2010].

The project final report is published as a book (in German) [Linssen et al., 2012].

This article describes the assessment of future wind power availability for charging EVs. These assessments also rely on results from the other project parts which are not described in detail here.

We start with the general grid load and wind power production. The energy demand and the usage and charging of EVs are determined, and finally the energy balance for the scenario years 2020 and 2030 is assessed.

The potential for wind energy production and usage is first assessed with the assumption of unlimited transfer capabilities of the grid. In chapter 0 the grid limitations are addressed, the details of which are published separately [Mischinger et al., 2012].

## II Scenario

This publication aims to assess the effects of a given fleet of EVs rather than predicting the probable EV deployment, therefore the build-up of a fleet of EVs is postulated. The total number of EVs is assumed to be 1 million in 2020 and 6 million in 2030, as aimed at by the German Federal Government [BMU, 2011].

The assumed development of the energy system is based on the objectives of the Energy Concept 2010 of the German Federal Government [BMW & BMU, 2010], supplemented by the nuclear energy phase out decreed in 2011. Given these

objectives, the power plant and wind turbine capacities installed in 2020 and 2030 are derived from calculations with the energy system model IKARUS (described e. g. in [Linssen et al., 2012]). The offshore capacities assumed in the NET-ELAN scenario are approximately reached if each offshore project for which an application was submitted [dena, 2011] will be finished within two years after planned start of construction. The wind turbine capacities in the NET-ELAN scenario are shown in Table 1. For comparison, Table 1 also shows the capacities in the base scenario in the concretisation of the Energy Concept 2010 by [Nagl et al., 2010; Schlesinger et al., 2010].

The dena website also provides the locations of the existing and planned wind parks. For each wind park assumed to be in operation in 2020 (2030), the wind speeds measured at the nearest of the measuring platforms FINO 1 to 3 [FINO platforms, 2012] are used to assess the potential wind power production. Table 1 also shows the allocation of installed wind park power to the three FINO locations.

**Table 1: Assumed wind turbine capacities in NET-ELAN and Energy Concept Scenarios 2010**

	2020 NET-ELAN [GW]	2020 Concept Scenarios [GW]	2030 NET-ELAN [GW]	2030 Concept Scenarios [GW]
onshore	29	33.3	45.4	33.7
offshore	6	7.6	18	12.6
... near FINO 1	5		15	
... near FINO 2	0.8		2.7	
... near FINO 3	0.2		0.3	

Source: NET-ELAN project, IEK-STE 2012  
Energy Scenarios for an Energy Concept [Nagl et al., 2010; Schlesinger et al., 2010]

### III General grid load and wind power production

To calculate the fluctuations of the wind power production, the electricity demand and the charging demand of EVs, a time dependent model with at least hourly resolution is required.

To assess the time series of the grid load and electricity generation in 2020 and 2030, the exact approach is separately assessing the time series of the power generation from photovoltaic, wind, other renewables, and power consumption, and extrapolating each of them to 2020 and 2030. As some of these values were not available, an approximate approach is chosen:

The assessment is based on data from the years 2007 and 2010, since the year 2007 is an example of a good wind year (wind index 106 %) and 2010 of a weak

wind year (wind index 74 %, source: [Bundesverband WindEnergie, 2012], verified by our own calculations with the data from German transmission system operators (TSOs)).

The time series of onshore wind power production for 2007 and 2010 are taken from the data supplied by the German TSOs, available from their websites [50Hertz Transmission, 2011a; amprion, 2011a; TenneT, 2011a; TransnetBW, 2012b]. The offshore wind power production in 2007 and 2010 was neglectable. The time series of “vertical grid load” for 2007 and 2010 are taken from the data supplied by the German TSOs, available from their websites [50Hertz Transmission, 2011b; amprion, 2011b; TenneT, 2011b; TransnetBW, 2012a]. The vertical grid load is defined as the total power transferred from the transmission grid to distribution grids and consumers. Up to 2012 nearly all renewable power sources (including wind farms) were connected to distribution grids (110 kV and lower, Table 2, source: our own evaluation of [Engel, 2012]), so the vertical grid load is the consumption minus production from renewables (minus production from small scale conventional plants). By adding the wind power to the vertical grid load, time series are derived which are independent from wind power production. Because charging at night is the focus of the analysis, photovoltaic production can be neglected.

**Table 2: Sum of installed electric power from renewable sources, by voltage level of grid connection, as of Oct. 2012**

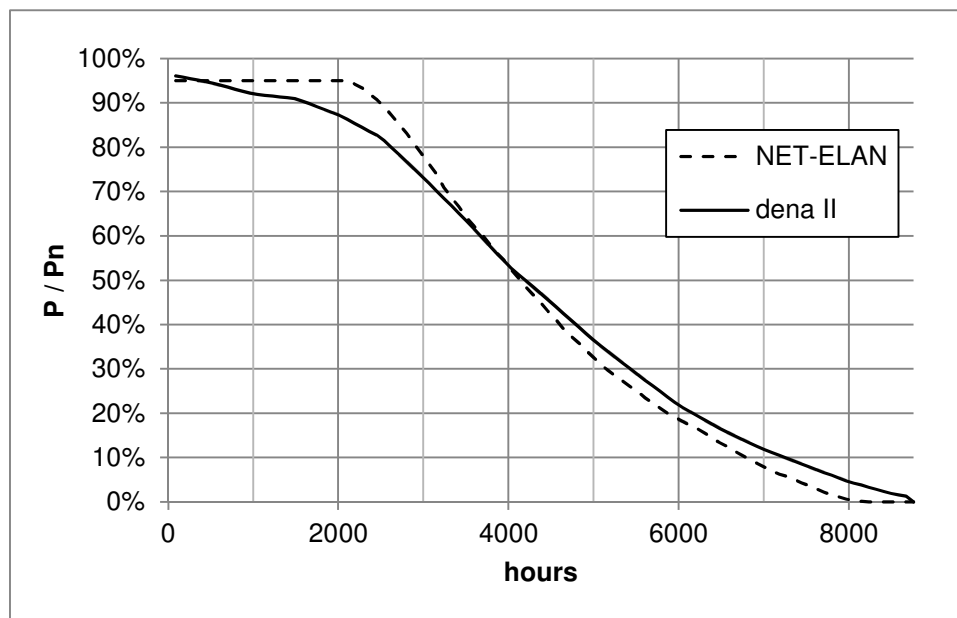
	geotherma l [MW]	gases [MW]	biomass [MW]	hydro [MW]	wind [MW]	solar electric [MW]
Extra High Voltage (220-380 kV)	0	0	22	4	1213	4
Extra High / High Voltage	0	4	2	12	229	1
High Voltage (110 kV)	0	75	279	169	9550	1182
High Voltage / Medium Voltage	0	24	292	103	4043	258
Medium Voltage (20 kV)	4	504	4332	1014	14784	7105
Medium Voltage / Low Voltage	1	13	237	40	84	811
Low Voltage (230/400 V)	3	24	577	253	198	18223
Source: Own assessment based on [Engel, 2012]					IEK-STE 2012	

The time series of onshore wind power in 2020 and 2030 are extrapolated from the 2007 (2010) time series by the ratio of installed onshore wind turbine capacity. The time series of the offshore wind power in 2020 and 2030 are derived from the time series of the wind speed measured in 2007 and 2010 on the offshore measuring platforms FINO 1 to 3 [FINO platforms, 2012] in 90 m above sea level (hub height of

typical offshore wind turbines) which are available from the FINO database<sup>1</sup> [BSH, 2011]. To each offshore wind park the wind speed of the nearest FINO measuring platform is assigned. Table 1 shows how the wind park capacities are assigned to the three FINO locations. The electrical power available from the wind turbines is calculated from the wind speeds using a typical power curve for offshore wind turbines and multiplied by the offshore wind turbine capacity in 2020 and 2030.

This derivation of the future wind power production in the NET-ELAN project is basically similar to the derivation in the dena Grid Study II [dena, 2010]. Although the dena Grid Study II uses a more detailed modelling, the duration curve of the wind power production modelled in NET-ELAN is in quite good agreement with that in the dena Grid Study II (Figure 1).

**Figure 1: Duration curves of offshore wind power in the NET-ELAN project and in the dena Grid Study II**



Sources: dena Grid Study II [dena, 2010]

and own calculation from FINO database [BSH, 2011]

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## IV Energy demand of electric vehicles

The specific energy consumptions of the EVs were estimated using detailed mathematical models of the cars, performing the Artemis and some measured real-world driving cycles, including consumption of ancillary systems and losses in the battery and the charger. The estimated energy demands for the Artemis driving cycle are close to those for the measured real-world driving cycle “commuter” and used for

<sup>1</sup> The FINO platforms and database are funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

assessing the energy drawn from the grid. Three EV sizes were modelled: mini, subcompact, and compact, and three drive train concepts: pure battery vehicles (BEV) with a driving range of 120 km, EV with range extender (REEV) with an electrical driving range of 50 km (in charge depleting mode, CDM) and plug-in hybrid EV (PHEV) with an electrical driving range of 30 km (CDM). The BEV is limited to a daily driving distance of 120 km, the REEV and PHEV cover distances above the electrical range by their internal combustion engines (i. e. in charge sustaining mode). The energy demands (Table 3) include a decrease over the manufacturing year due to technical improvements and the penetration of new vehicles in the fleet.

**Table 3: Shares of EV types and their energy demand**

	compact cars, fleet share	subcompact cars, fleet share	mini cars, fleet share	all sizes, average energy demand [kWh / 100 km]	
				in 2020	in 2030
BEV	16.7 %	20 %	10 %	17.7	15.7
REEV	16.7 %	20 %	0 %	18.0	16.1
PHEV	16.7 %	0 %	0 %	20.0	17.7
Source: NET-ELAN project				IEK-STE 2012	

The average daily driving distance of the EV was derived from the distribution of daily driving distances of privately used passenger cars from the statistical survey “Mobility in Germany 2008” [infas & DLR, 2009]. Some investigations make assumptions on future EV usage, e. g. [Metz & Doetsch, 2012] assume that only cars with a yearly mileage of 12,500 to 20,000 km will be substituted by an EV. However, future EV usage is influenced by more than just economic criteria and could be higher or lower than today's, so it is here assumed that driving distances of future EVs will be similar to today's average cars.

With these assumptions the total energy demand of 6 million BEVs in 2030 is 10.7 TWh/a, in contrast to 17 TWh/a in [Metz & Doetsch, 2012], partly because all cars are taken into account, including those with lower yearly mileage, partly because of the lower energy demand per km. As the REEV and PHEV cover daily distances above 30 km or 50 km with their ICE, the fleet energy demand with shares of BEV, REEV and PHEV as in Table 3 is lower, about 9.8 TWh/a.

## V Time dependent usage and charging of electric vehicles

In the project, only home charging is modelled. This was decided for the following reasons:

Grid interaction is only possible when the EV is parked. Although charging on-the-road seems technically possible [Shwartz, 2012; Yu et al., 2011], costs are expected to be prohibitive.

A charging connection must be available where the EV is parked.

The car user must connect the EV to the grid. Also here, wireless (inductive) charging is technically possible [BBC News, 2012] but assumed not to be generally applied because of high costs.

The evaluation of the German nationwide survey of driving habits “MiD 2008” [infas & DLR, 2009] revealed that 92 % of the daily driving distances can be covered purely electrically with a BEV and 75 % with a REEV if the battery is only charged once a day, after returning from the last trip of the day. In the case of urban driving profiles measured in the project, these shares are 95 % and 88 %. Additional charging during the day increases these shares only marginally.

The survey “MiD 2008” also indicates that the cars are parked at home for the majority of time ([Metz & Doetsch, 2012] come to the same conclusion), and that the majority of privately used cars have a dedicated parking or garage near the home. That allows a private charging connection to be established with low costs, whereas public charging stations are costly [Schroeder & Traber, 2012].

Connecting the EV to the grid is an extra effort for the user, so the user may not be willing to do this if it is not required for his own driving requirements. Several publications assume that the EV is connected to the grid whenever it is parked [Capion, 2009; Ekman, 2011], however the same article [Capion, 2009] admits that this is unrealistic. At least the benefit from connecting must justify the effort, therefore [Rehtanz & Rolink, 2009] assume that the EV is connected to the grid only if parked for longer than 1 hour.

It is therefore assumed here that the EV is connected to the grid only after returning home from the last trip of the day and disconnected just before starting the first trip of the next day. For example [Dallinger et al., 2011] make a similar assumption. While being connected, charging can either be uncontrolled (“dumb”), which means that charging starts as soon as the EV is connected to the grid and ends when the battery is fully charged, or it can be controlled in various ways.

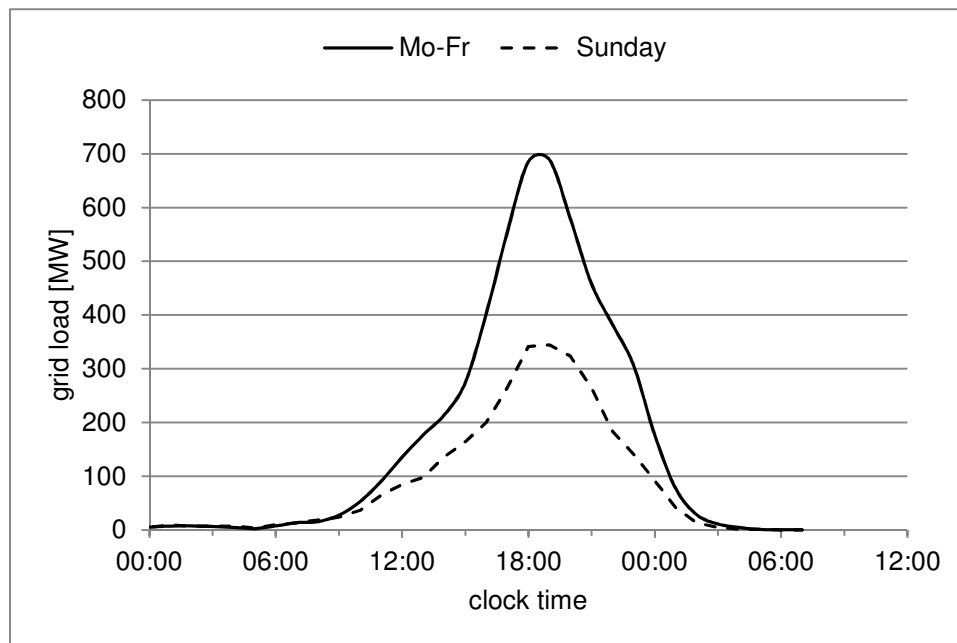
Up to 2020, the charging power at home is assumed to be 3.3 kW which is the maximum active power available at a standard 230 V 16 A connection with a power factor of 0.9 allowing for the non-sinusoidal current drawn by the charger. In 2030, the availability of three-phase charging with 9.9 kW is assumed. In all of the modelled car types this charging power is within the design limits of the battery.

For **uncontrolled charging**, only a part of the EVs are charging at the same time, because they return home at different times, therefore the maximum grid load for 1



million EV in 2020 is 700 MW (Figure 2), in contrast to 3300 MW if charging of all EVs would start at the same time. But this maximum of the charging load will occur at about 6 pm, when at winter time also the other grid loads are at maximum. That can cause problems particularly for the distribution grid, described in detail in the final report [Linssen et al., 2012].

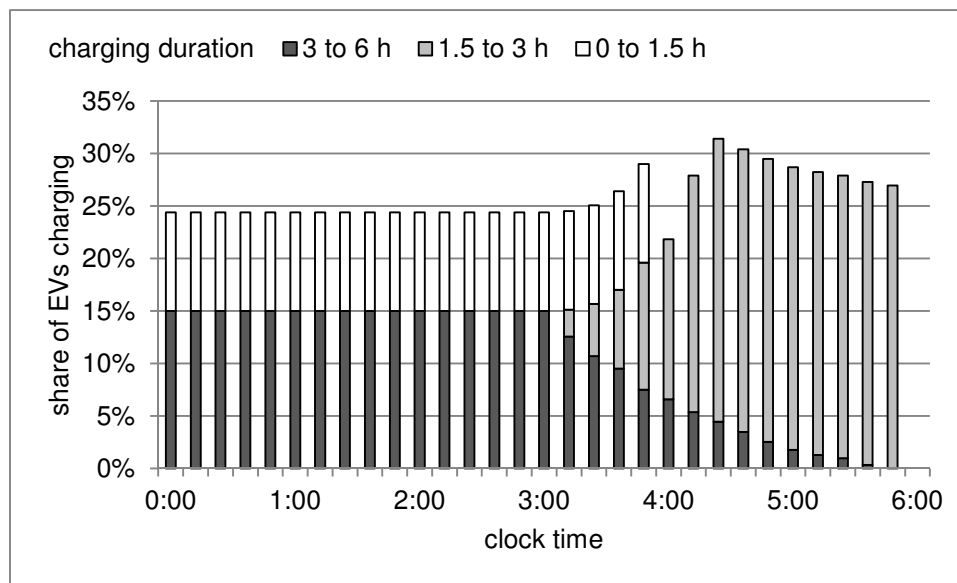
**Figure 2: Grid load caused by uncontrolled charging of 1 million EV in 2020**



Source: Own calculations based on “Mobility in Germany 2008” [infas & DLR, 2009]

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The simplest mode of **controlled charging** is shifting the charging into off-peak times. The grid load minimum in Germany is between about midnight and 6 am. In order to achieve a nearly constant charging load between 0 and 6 am the statistically distributed charging times ranging from some minutes to 6.4 hours (for the BEV full driving range of 120 km) must be taken into account. A very simple control algorithm could be as follows: The 15 % of the EVs having a charging need of 3 hours or more start charging at midnight. Charging of each of the 27 % of EVs needing 1.5 to 3 hours starts at a time so that charging is finished at 6 am. The charging times of the 58 % of EVs needing less than 1.5 hours are evenly distributed between midnight and 4 am. The resulting course of the share of simultaneously charging EVs over time is not perfectly even, ranging from 22 % to 31 % (Figure 3), but much better than a simultaneous start of all charging (100 %) at midnight.

**Figure 3: Time shifted charging in 2020**

Source: Own calculations based on “Mobility in Germany 2008” [infas & DLR, 2009]

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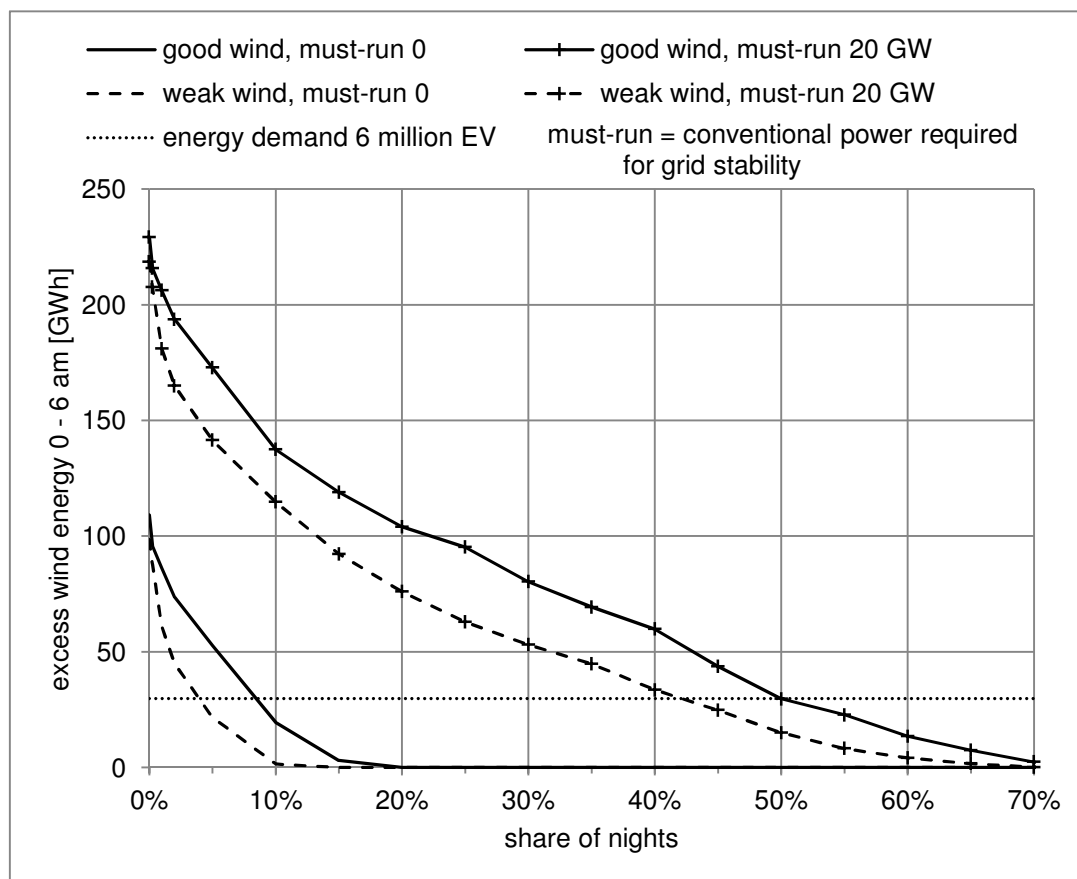
With a charging power of 9.9 kW (assumed for 2030), all charging times are below 2 hours and can be suitably distributed between 0 and 6 am, giving a smooth grid load.

## VI Energy balance without grid restrictions

Because of its statutory priority, all electric power from renewable energies is consumed unless its production exceeds the consumption (including possible export) or the grid stability requires its limitation. As long as all renewable power is already utilized in other loads, the additional load of EVs must be satisfied by increasing the production of conventional power plants. Renewable power is only available for charging EVs if this power could not be used otherwise. The amount of excess renewable power depends not only on the renewable power production and the power consumption but also on the amount of conventional power required to stabilize the grid (so-called must-run capacity). The dena Grid Study I [dena, 2005: p. 274] assessed that in 2020 with an installed wind power capacity of 48 GW, 20 to 30 GW of conventional power plant production are needed to be able to supply negative control power (that is power which can be reduced when needed for balancing production and consumption). The FGH assessed that currently (2012 to 2014) in the German grid 8 to 25 GW of conventional power plant production must run to be able to control the active power balance and 4 to 20 GW for delivering reactive power [FGH et al., 2012]. It is assumed here that 20 GW of conventional power production are needed to ensure grid stability. To show the impact of the must-run capacity, the results for zero must-run are pointed out, too.

Figure 4 shows the distribution of potential excess energy from wind power in the hours between midnight and 6 am of each night, for the year 2030. In a good wind year (solid lines) with 20 GW must-run power, excess energy is available in 70 % of the nights, and it meets the daily (Mo–Fr) energy demand of 6 million EVs (dotted line) in 50 % of the nights. On the other hand, if no must-run power is required, excess energy is available in only 20 % of the nights and meets the EV demand in 8 % of the nights. The available excess energy is even less for a weak wind year (dashed lines). The utilization of wind power is limited by the charging demand of the vehicles, i. e. each night only as much wind power can be charged into the batteries of the vehicles as was discharged by driving during the past day (dotted line). The capability of the vehicles to utilize wind power could be increased if the battery would not be fully charged in nights with low wind, but that would mean a decrease of available driving range which will probably not be accepted by the vehicle users.

**Figure 4: Distributions of excess electrical energy from wind in 2030**



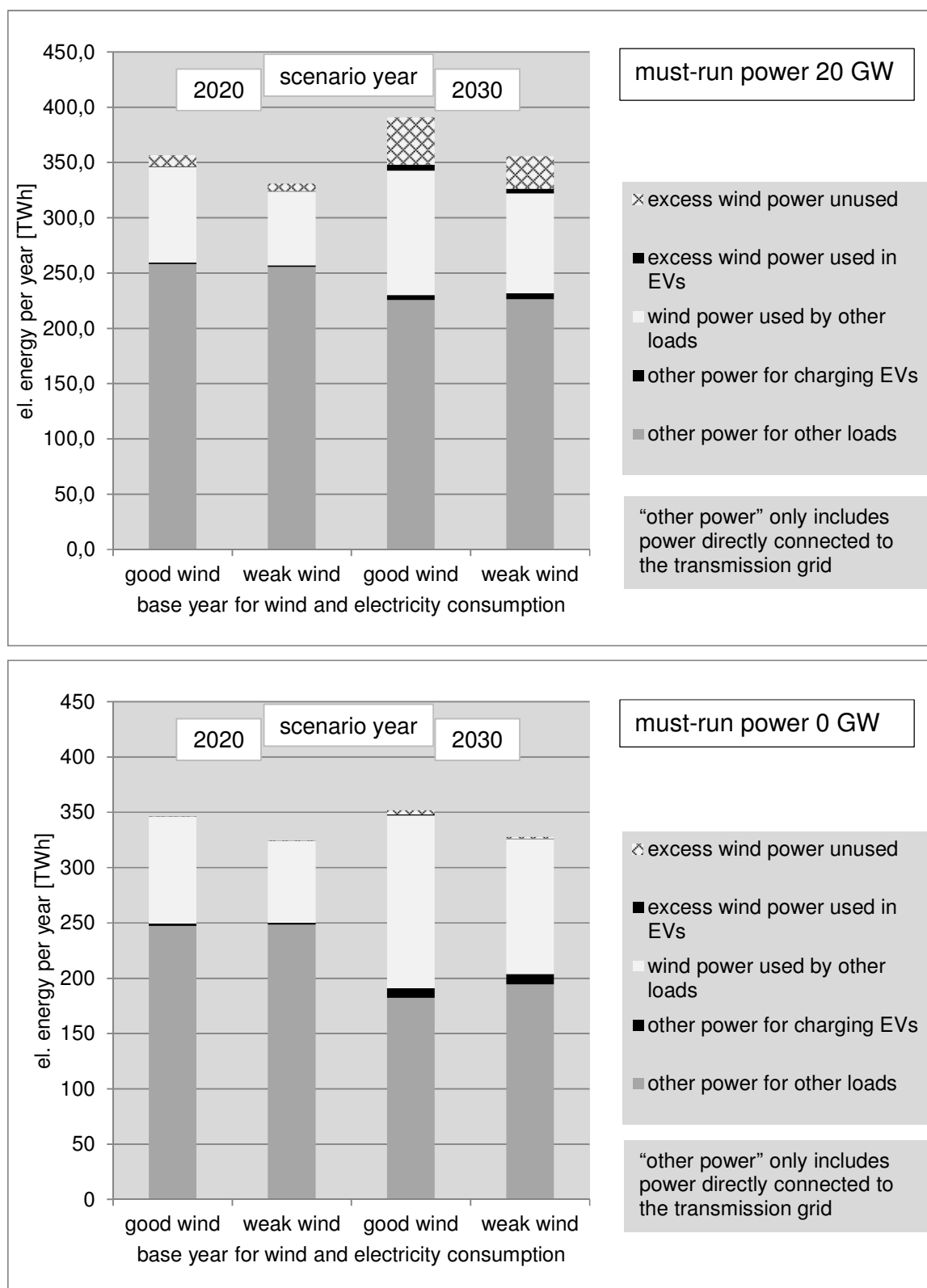
Source: Own calculations based on grid load and onshore wind power data from German TSOs [50Hertz Transmission, 2011a, 2011b; amprion, 2011a, 2011b; TenneT, 2011a, 2011b; TransnetBW, 2012a, 2012b]

and offshore wind power based on FINO data [BSH, 2011]

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Figure 4 shows only the energy balance of each night. As the excess wind power is not evenly distributed over the night hours and the charging power of the EVs is limited, the excess wind energy which actually can be utilized by EVs is even lower. The yearly sums of utilized and non-utilized wind power are shown in Figure 5. In 2020, the effect of 1 million EVs is so small that it can hardly be seen. 6 million EV in 2030 have a noticeable but not dramatic effect and can be powered without extensions of the electric power system (described in detail in [Linssen et al., 2012]). Note that in Figure 5 “other power” only includes the power directly fed into the transmission grid (380 and 220 kV voltage level) and the total energy in this figure is lower than the total electricity consumption.

In 2030 about 50 % of the energy need of the EVs can be met by utilizing excess wind power, but only if 20 GW of must-run power are required for grid stabilization. If zero must-run power would be required, even in 2030 most wind power could be utilized in other loads and hardly any excess wind power is available for charging the EVs.

**Figure 5: Yearly energy balance including wind power and EV charging**

Source: Own calculations based on grid load and onshore wind power data from German TSOs [50Hertz Transmission, 2011a, 2011b; amprion, 2011a, 2011b; TenneT, 2011a, 2011b; TransnetBW, 2012a, 2012b] and offshore wind power based on FINO data [BSH, 2011]

## **VII Energy balance with grid restrictions**

For assessing the capabilities of the transmission grid to deliver EV charging power and to absorb wind power, a model of the German transmission grid including the power plant portfolio was developed for 2020 and 2030. The details are published, see [Mischinger et al., 2012].

The calculations with the grid model show that in the scenario year 2020 the share of excess wind energy useable in EVs with controlled charging is limited to 7.5 % by grid bottlenecks, compared to the potential of 8.4 % with no grid restrictions. In the scenario year 2030 the limitation is more significant, 8 % compared to 15 % without grid restrictions, because the grid capacity does not keep up with the increased installed wind turbine power. The share of charging energy supplied by wind energy in 2030 is limited by grid bottlenecks to 30 %, compared to a potential of 50 % without grid restrictions.

## **VIII Conclusions**

1 million EV have hardly any effect on the energy balance, 6 million have a noticeable but not dramatic effect.

In the scenario, significant excess wind power is only available if it is assumed that 20 GW of conventional power is required for grid stabilization. If no minimum of conventional power is required, all wind power – as far as it can be transported by the transmission grid – can be utilized by other consumers, so that all charging power of the EVs must be delivered by increased production from conventional power plants.

Without grid restrictions and a must-run power plant capacity of 20 GW, in the model year 2030 about 15 % of the excess wind power can be utilized for charging EVs and can supply up to 50 % of the energy needed by the EVs. The utilization of wind power is limited by the daily charging demand of the cars.

Taking bottlenecks of the transmission grid into account, in the model year 2030 a significant amount of wind power cannot be transported to the consumers, reducing the share of EV charging supplied from wind power from 50 % to 30 %. However, the reinforcements of existing and additions of new high voltage power lines as defined in the recent grid development plan [TenneT TSO GmbH et al., 2013] will remove most of these bottlenecks.

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